# Adjusted CERES SRBAVG Dataset for Climate Modelers

Norman G. Loeb[1], B. A. Wielicki[1], D.R. Doelling[1], G.L. Smith[2], D.F. Keyes[3], S. Kato[1], N. Manalo-Smith[3] and T. Wong[1]

[1]NASA Langley Research Center, Hampton, VA

[2]National Institute of Aerospace (NIA), Hampton, VA

[3]Science Systems and Applications, Inc. (SSAI), Hampton, VA

May 6th, 2008, CERES Science Team Meeting, Newport News, VA

# Motivation

- The 5-year global mean CERES net TOA flux from SRBAVG_GEO is 6.5 $Wm^{-2}$.
- Observed ocean heat content data and model simulations indicate that the Earth is now absorbing 0.85±0.15 $Wm^{-2}$ more solar energy than it radiates to space as heat (Hansen et al., 2005).
- To use Earth Radiation Budget (ERB) data for climate model evaluation, estimating the Earth's annual global mean energy budget, and to infer meridional heat transports, one must account for inconsistencies between global long-term average net TOA flux and heat storage within the Earth-atmosphere system.
- Our goal is to produce such a dataset by adjusting SRBAVG_GEO SW & LW TOA fluxes within their range of uncertainty.

# Approach

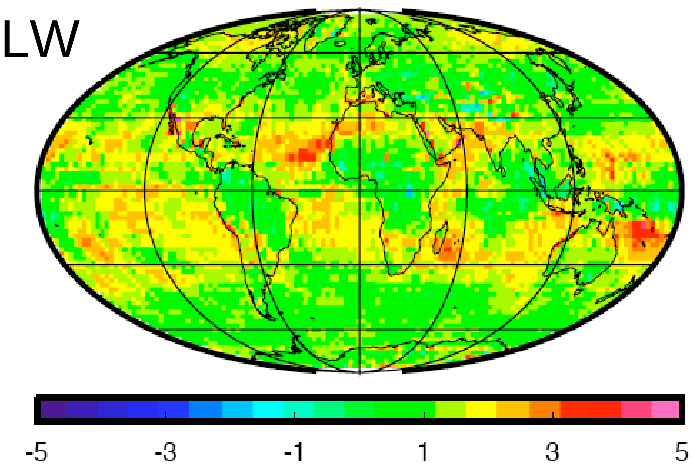
- The first step is to quantify uncertainties in CERES net TOA flux.
- Next, apply an objective constrainment algorithm to adjust SW and LW TOA fluxes within their range of uncertainty to remove the inconsistency between average global net TOA flux and heat storage in the Earth-atmosphere system.
- Produce a new “high-resolution” clear-sky TOA flux climatology by inferring TOA flux from both CERES and MODIS radiance data.

# Global Mean Clear and All-sky SW, LW and Net TOA Radiative Fluxes for Satellite-based Data Products

| Product Name | ERBE S-4 | CERES | | | GEWEX SRB Version 2.86 | ISCCP FD |
|---|---|---|---|---|---|---|
| | | ES-4 Ed2_rev1 | SRBAVG-nonGEO Ed2D_rev1 | SRBAVG-GEO Ed2D_rev1 | | |
| Time Period | 02/85 – 01/89 | 03/00 – 02/2005 | | | | |
| Solar Irradiance | 341.3 | 341.3 | 341.3 | 341.3 | 341.8 | 341.5 |
| LW (All-sky) | 235.2 | 239.0 | 237.7 | 237.1 | 240.4 | 235.8 |
| SW (All-Sky) | 101.2 | 98.3 | 96.6 | 97.7 | 101.7 | 105.2 |
| **Net (All-Sky)** | **4.9** | **4.0** | **7.0** | **6.5** | **-0.3** | **0.5** |
| LW (Clear-Sky) | 264.9 | 266.6 | 266.4 | 264.1 | 268.1 | 262.3 |
| SW (Clear-Sky) | 53.6 | 49.3 | 51.2 | 51.1 | 54.5 | 54.2 |
| Net (Clear-Sky) | 22.8 | 25.4 | 23.7 | 26.2 | 19.2 | 25.0 |
| LW CRE | 29.7 | 27.6 | 28.7 | 27.0 | 27.7 | 26.5 |
| SW CRE | -47.6 | -49.0 | -45.4 | -46.6 | -47.2 | -51.0 |
| NET CRE | -17.9 | -21.4 | -16.7 | -19.7 | -19.5 | -24.5 |

# CERES ERBE-Like minus nonGEO All-Sky TOA Flux Difference ($Wm^{-2}$)

LW



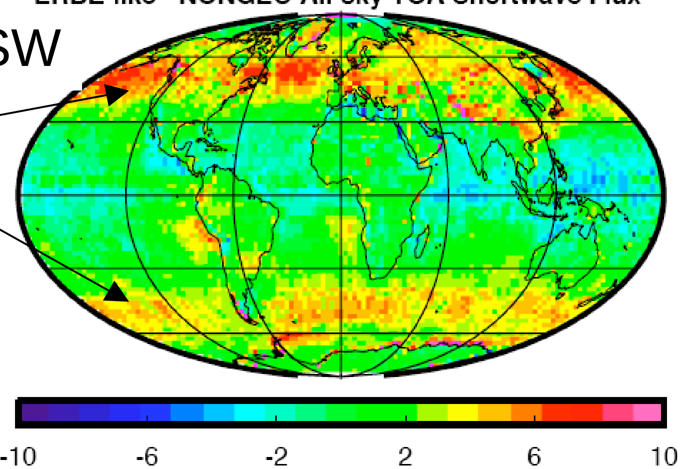

Global Mean Difference

1.3 $Wm^{-2}$

- Differences due to Scene iD + ADMs
- ERBE albedo increase with viewing geometry more pronounced at high latitudes.

ERBE-like - NONGEO All-sky TOA Shortwave Flux

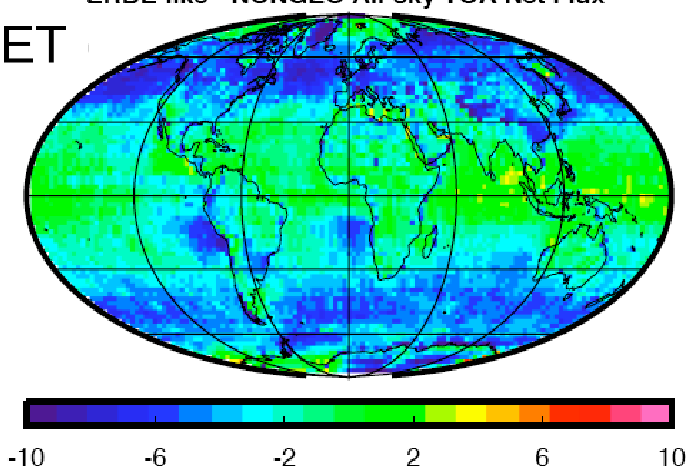
SW




1.7$Wm^{-2}$

ERBE-like - NONGEO All-sky TOA Net Flux

NET



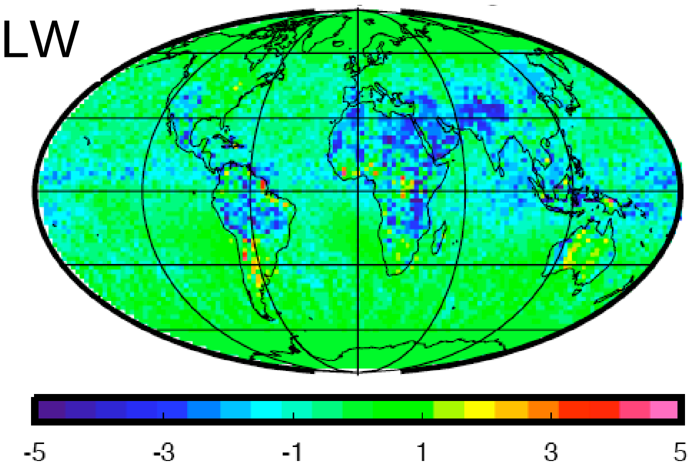

-3.0 $Wm^{-2}$

# GEO minus NONGEO All-Sky TOA Flux Difference ($Wm^{-2}$)

<u>Global Mean Difference</u>

- Differences due to temporal interpolation

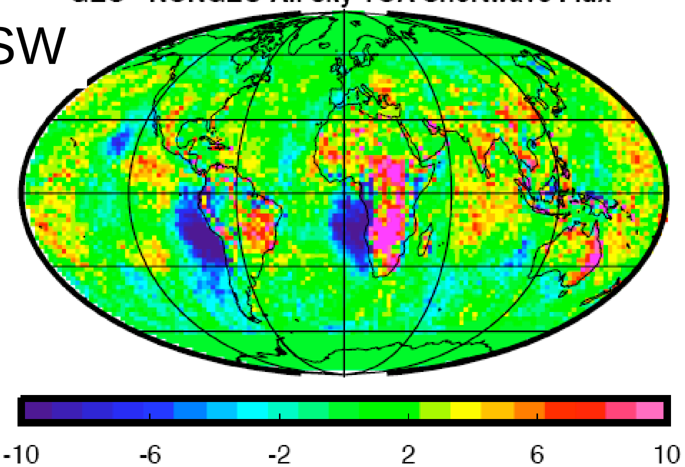
LW




$-0.6\ Wm^{-2}$

GEO - NONGEO All-sky TOA Shortwave Flux

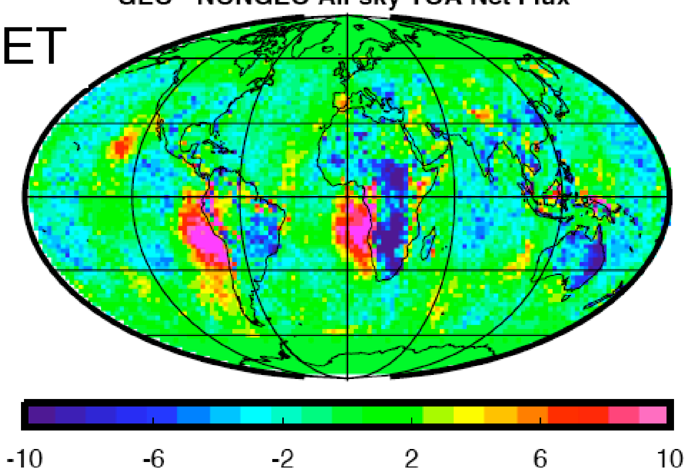
SW




$1.1\ Wm^{-2}$

GEO - NONGEO All-sky TOA Net Flux

NET




$-0.5\ Wm^{-2}$

# CERES TOA Flux Error Budget

| | Bias Errors of Known Sign ($Wm^{-2}$) | | | | |
|---|---|---|---|---|---|
| Error Source | Incoming Solar | Outgoing SW | Outgoing LW | Net Incoming | Comment |
| Total Solar Irradiance | +1 | 0 | 0 | +1 | Recent solar irradiance measurement vs assumed solar irradiance in CERES |
| Spherical Earth Assumption | +0.29 | +0.18 (+0.11) | -0.05 (-0.06) | +0.16 (+0.24) | Weighting latitude zones in geocentric vs geodedic coordinates. |
| Near-Terminator Flux | 0 | -0.3 | 0 | +0.3 (+0.15) | Discretization uncertainty in time-space averaging algorithm at $\theta_o$ >85° |
| Heat Storage | 0 | 0 | 0 | +0.85 | Hansen et al. (2005) |
| | Bias Errors of Unknown Sign ($Wm^{-2}$) | | | | |
| Source | Incoming Solar | Outgoing SW | Outgoing LW | Net Incoming | Comment |
| Total Solar Irradiance | ±0.2 | 0 | 0 | ±0.2 | Absolute Calibration (95% confidence) |
| Filtered Radiance | 0 | ±2.0 | ±2.4 (N)<br>±5.0 (D) | ±4.2 | Absolute Calibration (95% confidence) |
| Unfiltered Radiance | 0 | ±0.5 | ±0.25 (N)<br>±0.45 (D) | ±1.0 | - Instrument spectral response function<br>- Unfiltering algorithm |
| Radiance-to-Flux Conversion | 0 | ±0.2 | ±0.3 | ±0.4 | Angular distribution model error |
| Flux Reference Level | 0 | ±0.1 | ±0.2 | ±0.2 | Uncertainty in assuming a 20-km reference level |
| Time & Space Averaging | 0 | ±0.3 | ±0.3 | ±0.4 | Geostationary instrument normalization with CERES |
| Heat Storage | 0 | 0 | 0 | ±0.15 | Hansen et al. (2005) |

**Expected Range in Net TOA Flux: -2.1 $Wm^{-2}$ to 6.7 $Wm^{-2}$**

# Constrainment Algorithm

$$R_N = H + \varepsilon_{R_N} \quad \textbf{(1)}$$

$H$ = Global average heat storage.

$\varepsilon_{R_N}$ = Error in $R_N$ arising due to uncertainties in several factors $\rho_i$ involved in determining $R_N$ (e.g., instrument calibration, unfiltering, ADMs, etc.).

We wish to modify the parameters $\rho_i$ by some amount $x_i$ such that the revised $R_N$ is equal to *H*:

$$\hat{R}_N = R_N + \sum_i \frac{\partial R_N}{\partial p_i} x_i = H \quad \textbf{(2)}$$

$$\sum_i \frac{\partial R_N}{\partial p_i} x_i = -\varepsilon_{R_N} \quad \textbf{(3)}$$

The criterion for selecting the parameters to adjust is to choose the most likely set $x_i$ that satisfy Eq. (3) using a maximum likelihood estimate for the $x_i$.

This is solved using the method of Lagrange multipliers.

| ($Wm^{-2}$) | SRBAVG_GEO Ed2D_rev1 | | |
|---|---|---|---|
| | Original | Adjusted | Difference |
| Solar Irradiance | 341.3 | 340.0 | -1.3 |
| LW (All-Sky) | 237.1 | 239.6 | 2.5 |
| SW (All-Sky) | 97.7 | 99.5 | 1.8 |
| Net (All-Sky) | 6.5 | 0.87 | -5.6 |

# Results of Constraint Algorithm

| | Adjusted ERBE (Feb 1985- Apr 1989) | Adjusted ERBE (Feb 1985- Apr 1989) | Adjusted CERES (Mar 2000 – May 2004) | Adjusted CERES (This Study) (Mar 2000 – Feb 2005) | | |
|---|---|---|---|---|---|---|
| Product Name | Trenberth (1997) | Fasullo & Trenberth (2008) | Fasullo & Trenberth (2008) | CERES SRBAVG-nonGEO Ed2D_rev1_ADJ | CERES SRBAVG-GEO_Ed2D_rev1_ADJ | CERES SRBAVG-GEO_Ed2D_rev1_ADJ All-Sky & CERES-MODIS Clear-Sky |
| Solar Irradiance | **341.3** | 341.3 | 341.3 | 340.0 | 340.0 | **340.0** |
| LW (All-sky) | **234.4** | 234.4 | 238.5 | 240.2 | 239.6 | **239.6** |
| SW (All-Sky) | **106.9** | 106.9 | 101.9 | 98.4 | 99.5 | **99.5** |
| Net (All-Sky) | **0.0** | 0.0 | 0.9 | 1.38 | 0.87 | **0.87** |
| LW (Clear-Sky) | 264.9* | 264.9* | 269.1** | 269.2 | 266.9*** | 269.1 |
| SW (Clear-Sky) | 53.6* | 53.6* | 52.9** | 52.1 | 52.0 | 52.9 |
| Net (Clear-Sky) | 22.8* | 22.8* | 18.0** | 18.7 | 21.1 | 18.0 |
| LW CRE | 30.5* | 30.5* | 30.6** | 29.0 | 27.3 | 29.5 |
| SW CRE | -53.3* | -53.3* | -49.0** | -46.3 | -47.5 | -46.6 |
| NET CRE | -22.8* | -22.8* | -18.4** | -17.3 | -20.2 | -17.1 |

# High-Resolution Clear-sky Fluxes

- CERES SRBAVG clear-sky monthly mean TOA fluxes are provided for 1°x1° regions from CERES footprints identified as clear according to 1-km resolution MODIS data.
- Because of the coarse spatial resolution of CERES (20 km at nadir), only flux contributions from cloud-free regions occurring over relatively large spatial scales are considered.

  => Population is biased to certain meteorological conditions and geographical regions.

  => Clear-sky maps contain missing regions.
- An alternative approach is to recover clear-sky flux contributions at smaller spatial scales directly from MODIS radiances in cloud-free portions of CERES footprints.
- That is, determine gridbox mean clear-sky flux from an area-weighted average of:

  (i) CERES broadband fluxes from completely cloud-free footprints.

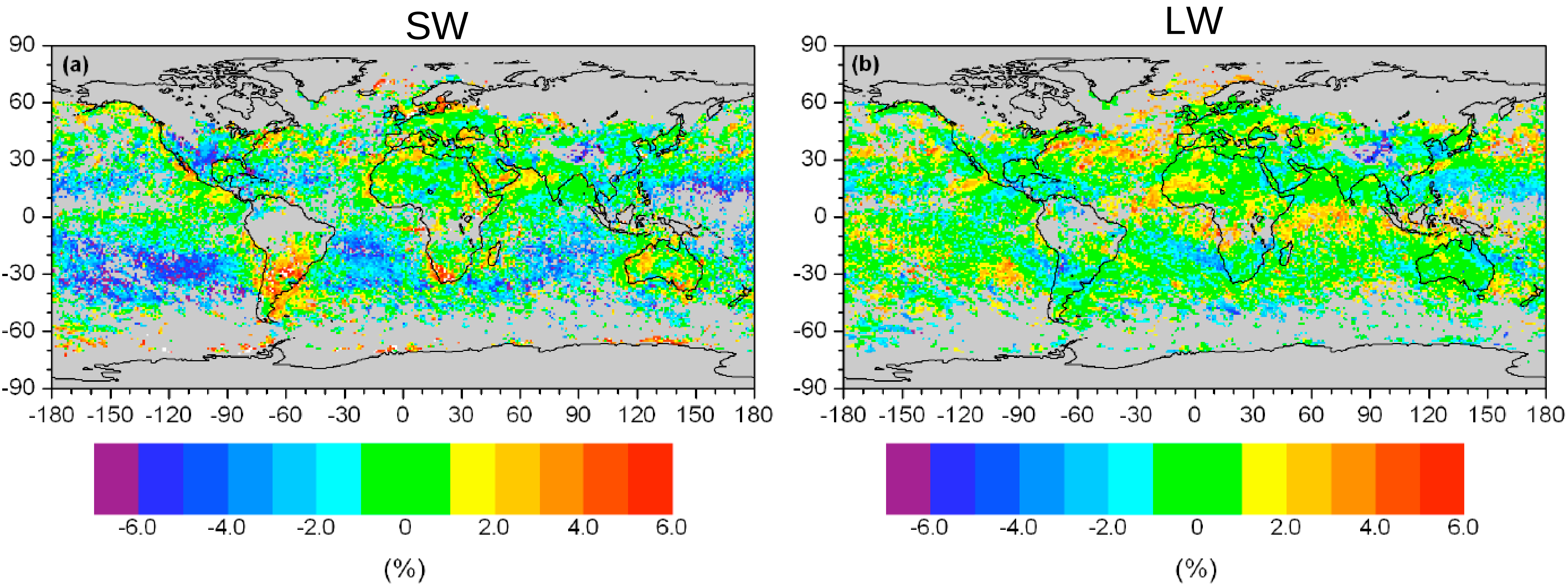
  (ii) MODIS-derived "broadband" clear-sky fluxes estimated from the cloud-free portions of partly and mostly cloudy CERES footprints.

- To convert MODIS narrowband radiance measurements to a broadband radiance estimate:

$$\hat{I}_{BB} = a_0 + \sum_{i=1}^{N_\lambda} a_i I_i$$

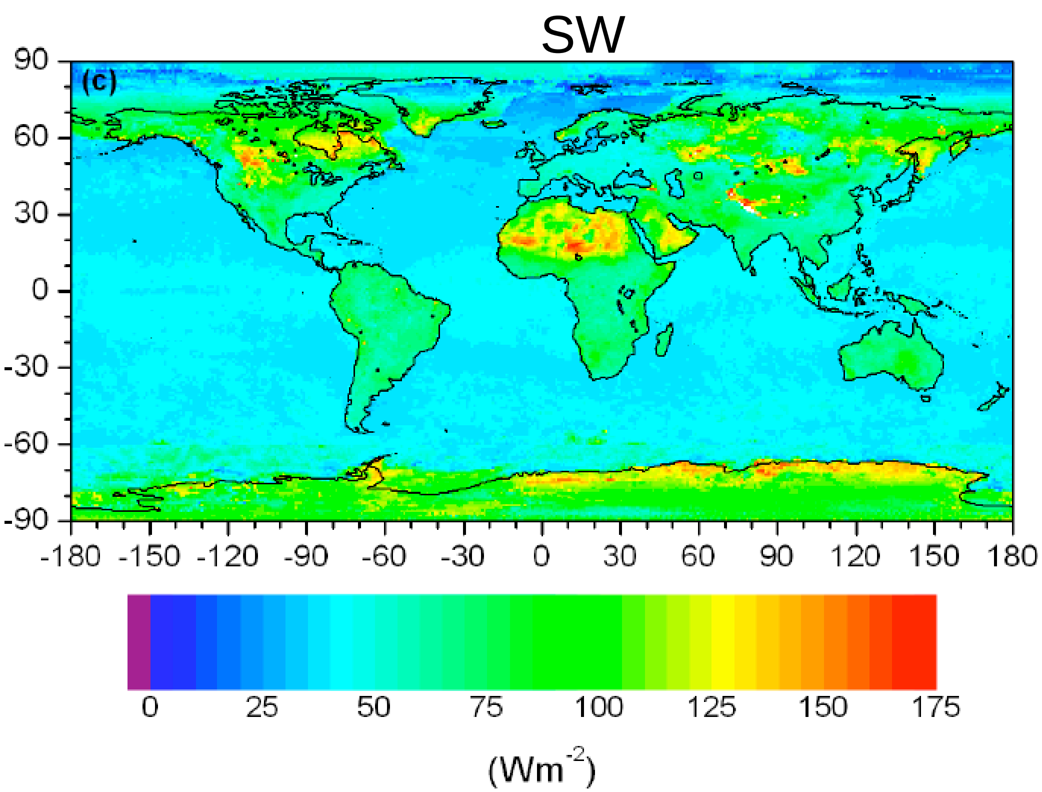
- The $a_i$'s are regression coefficients, and the $I_i$'s correspond to narrowband MODIS radiances averaged over the cloud-free part of a CERES footprint.
- "Broadband" MODIS radiances are converted to TOA radiative fluxes using CERES clear-sky ADMs.
- Regression coefficients are determined monthly by relating CERES radiances in cloud-free footprints with coincident MODIS narrow-band radiances.
- In the SW, 0.645 μm, 0.858 μm, & 1.632 μm MODIS radiances are considered. Separate regressions are developed for ocean, forests, savannahs, grasslands, dark and bright deserts. Separate $a_i$'s are determined for different viewing geometries.
- In the LW, 11 μm MODIS radiances are used for same sfc types as SW. Coefficients also depend upon precip water and VZA.

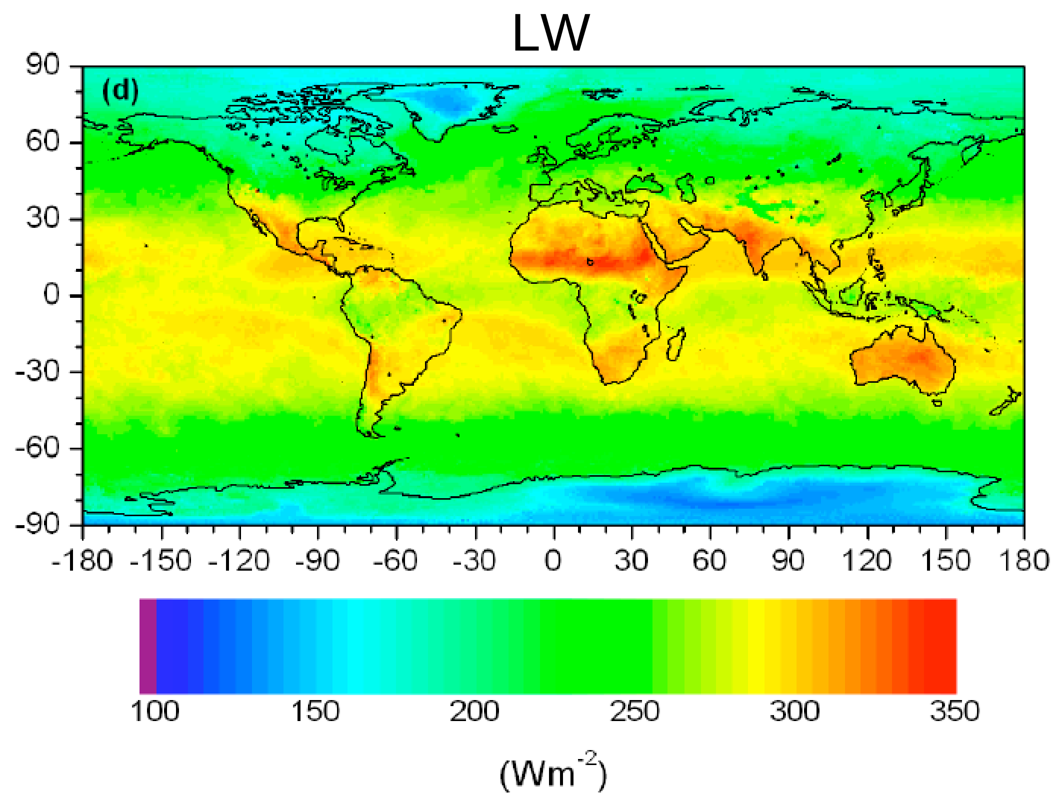
# Relative Bias in Clear-Sky TOA Flux due to Narrow-to-Broadband Regression (March 2002; Cloud-Free CERES Footprints Only)



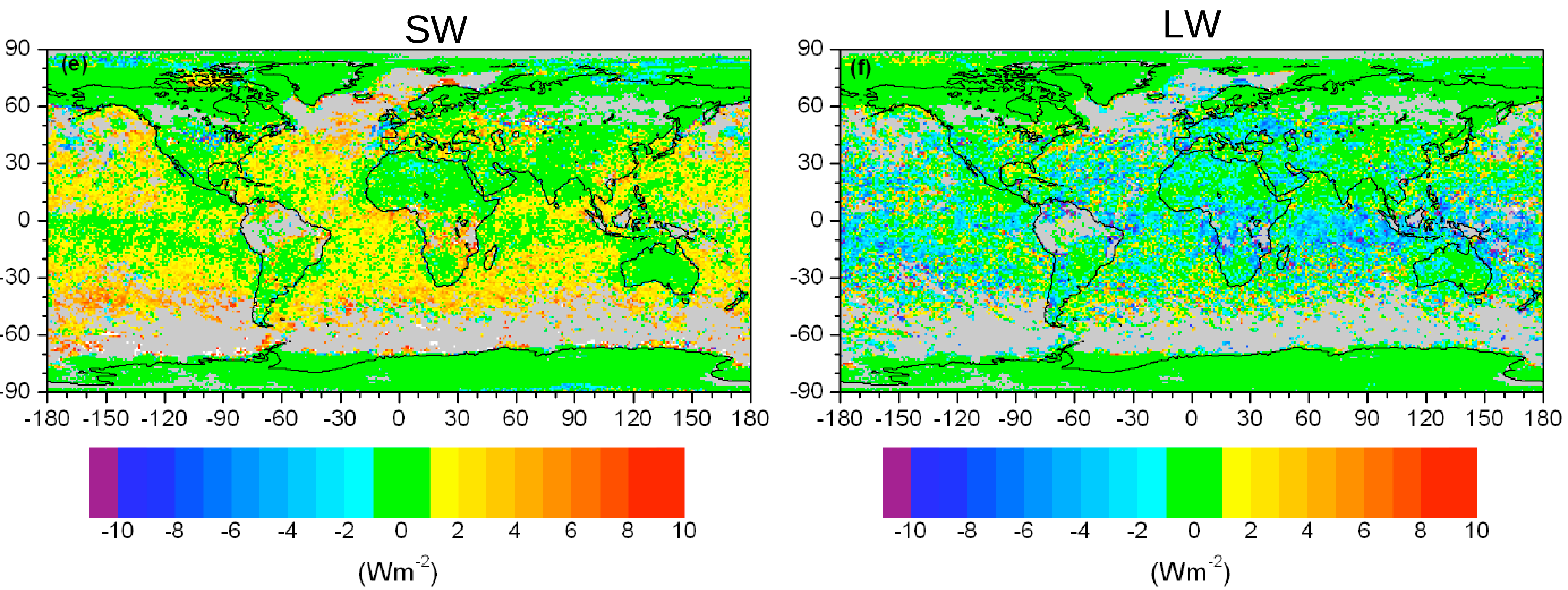

To minimize the influence of narrow-to-broadband regression errors on the final monthly mean clear-sky flux, the above errors are subtracted from mean fluxes derived from partly and mostly cloudy footprints.

# High-Resolution Clear-Sky TOA Flux
# (March 2002)



# High-Resolution Minus CERES-Only Clear-Sky TOA Flux
# (March 2002)



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|---|---|---|---|---|---|---|
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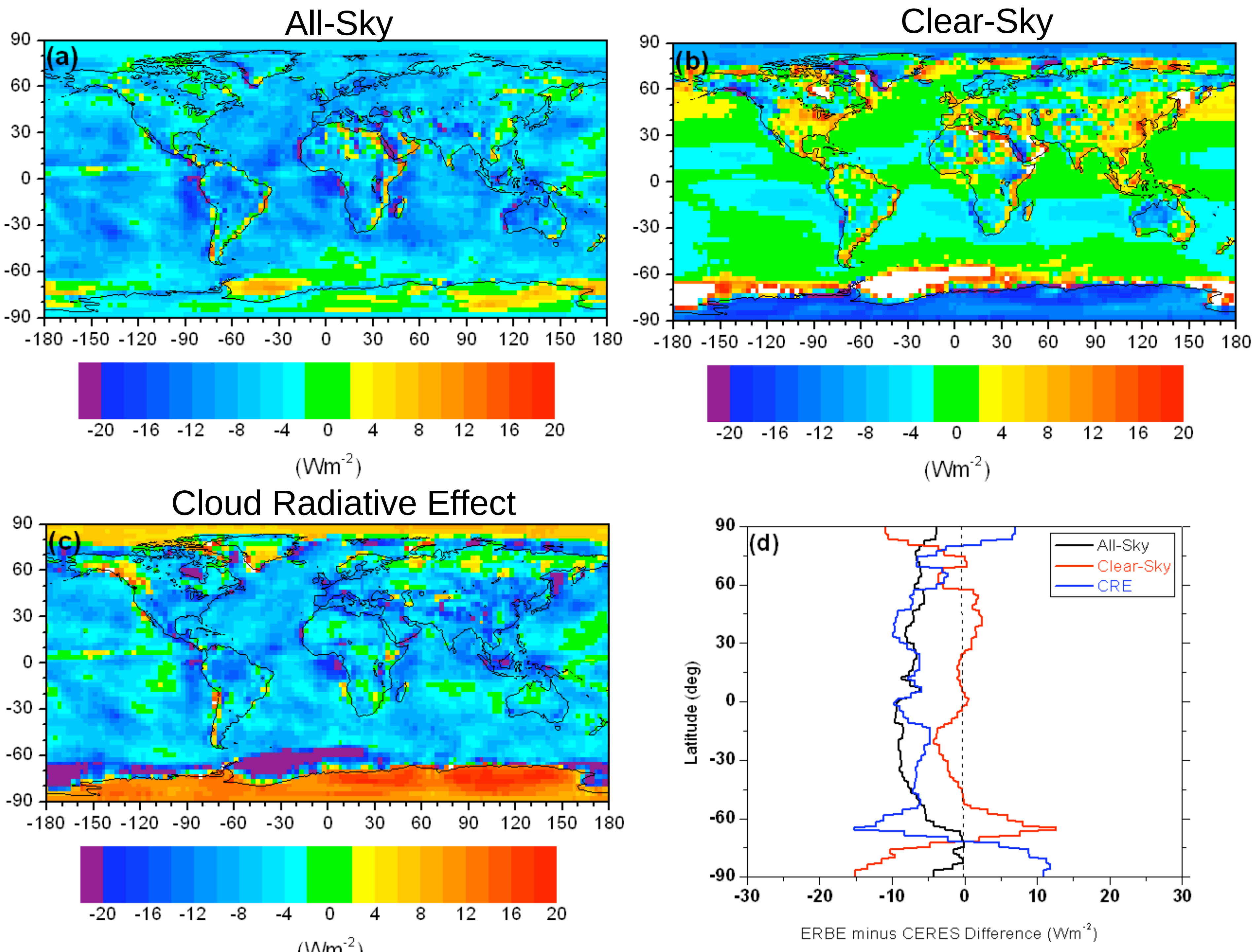
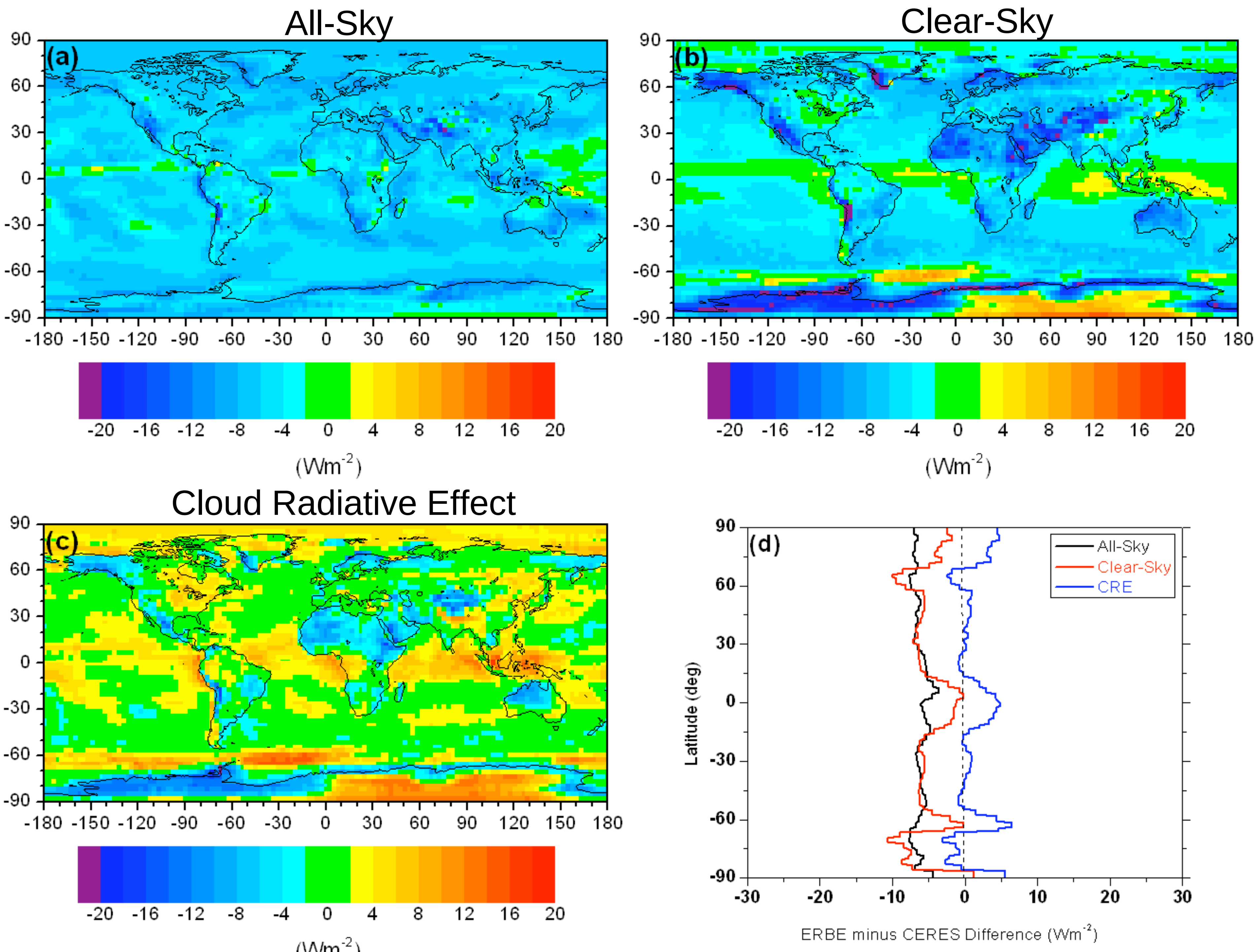
| Solar Irradiance | **341.3** | 341.3 | 341.3 | 340.0 | 340.0 | **340.0** |
| LW (All-sky) | **234.4** | 234.4 | 238.5 | 240.2 | 239.6 | **239.6** |
| SW (All-Sky) | **106.9** | 106.9 | 101.9 | 98.4 | 99.5 | **99.5** |
| Net (All-Sky) | **0.0** | 0.0 | 0.9 | 1.38 | 0.87 | **0.87** |
| LW (Clear-Sky) | 264.9* | 264.9* | 269.1** | 269.2 | 266.9*** | 269.1 |
| SW (Clear-Sky) | 53.6* | 53.6* | 52.9** | 52.1 | 52.0 | 52.9 |
| Net (Clear-Sky) | 22.8* | 22.8* | 18.0** | 18.7 | 21.1 | 18.0 |
| LW CRE | 30.5* | 30.5* | 30.6** | 29.0 | 27.3 | 29.5 |
| SW CRE | -53.3* | -53.3* | -49.0** | -46.3 | -47.5 | -46.6 |
| NET CRE | -22.8* | -22.8* | -18.4** | -17.3 | -20.2 | -17.1 |

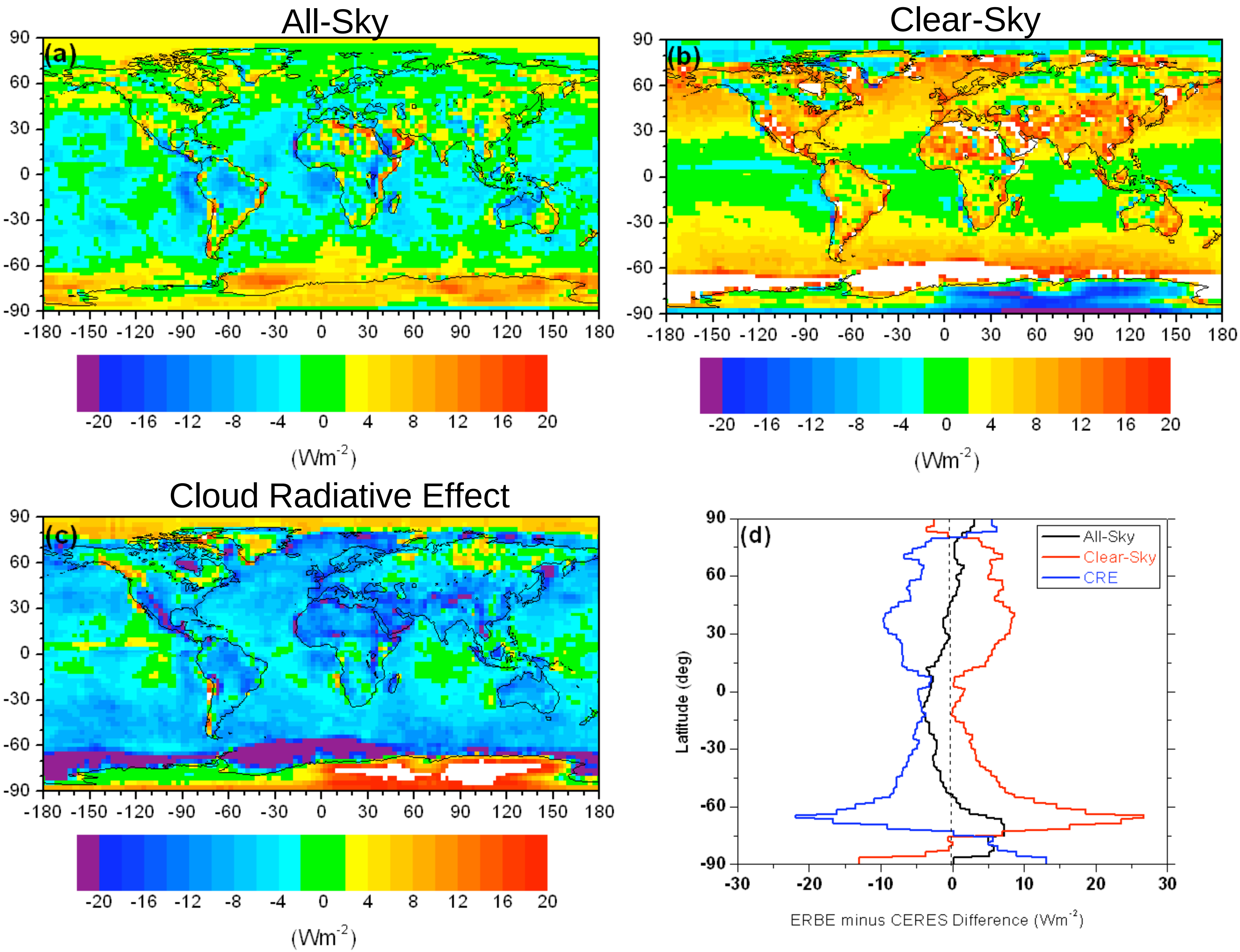
# Adjusted ERBE Minus Adjusted CERES Absorbed SW Radiation at TOA



# Adjusted ERBE Minus Adjusted CERES Outgoing LW Radiation at TOA



# Adjusted ERBE Minus Adjusted CERES Net Radiation at TOA



## Summary

- Adjusted CERES TOA fluxes differ markedly from those of Trenberth (1997).
- Dataset comprised of adjusted SRBAVG_GEO and high-resolution clear-sky TOA fluxes has been generated for first 5 years of CERES-Terra but not released to public yet.

  => Purposely small in size and in netCDF format.
  => Manuscript describing new dataset is ready for submission to J. Climate.
  ⇒ Website with graphical representation of monthly means has been produced but not made public yet.

- Dataset will be released pending approval from CERES science team.